BTeV Tracking System

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Fermilab

BTeV Director's CD-1 Review

March 30, 2004 Fermilab

OUTLINE

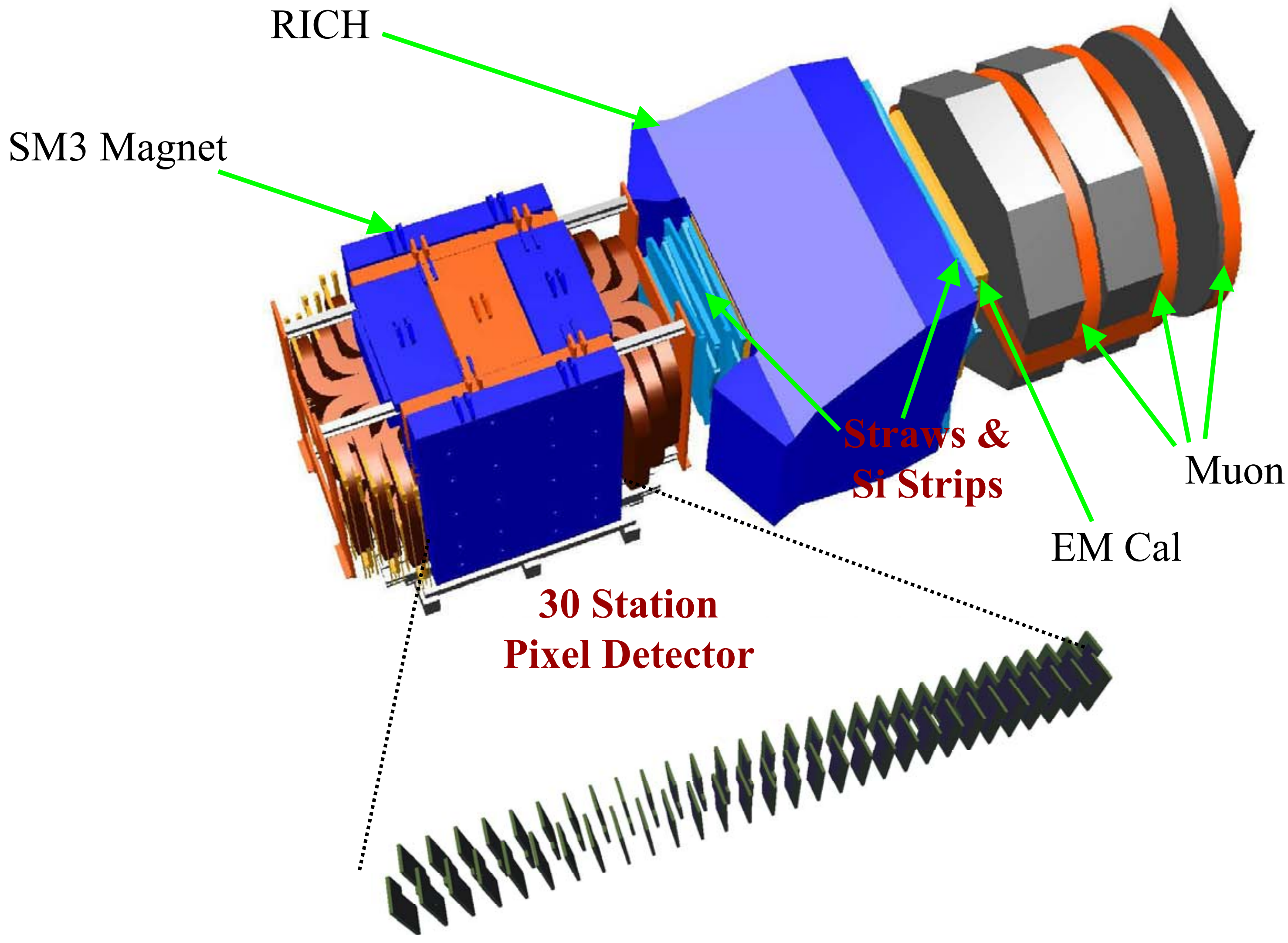
- BTeV Tracking System Overview
- Properties
- R&D: Responses to last Temple Review
- Technical Design
- Resource-loaded schedule
- Conclusion

BTeV Tracking System

- **Coverage**:
  - Aperture 300 mr
  - Momentum acceptance 1- >100 GeV/c
- **Spatial resolution for vertex detector:**
  - Better than 9 μm
- **Angular resolution**:
  - Better than 0.1 mr
- **Momentum resolution**:
  - 1% at 100 GeV/c
- **Can handle huge data rate and survive high radiation dosage**

- **Two Tracking Systems**
  - Pixel Vertex Detector (WBS1.2)
    - Precise vertex detection and crude momentum measurement capability
    - Fast info available for use in L1 vertex trigger
  - Forward Tracker
    - Precise momentum measurement, Ks/Λ detection, project tracks into RICH, EMCAL, Muon chambers
    - Combination of **Silicon strips (WBS 1.7)** near the beam and **Straw Chambers (WBS 1.6)** at large radius

BTeV Detector



Pixel Detector WBS 1.2

Fermilab: J. A. Appel, D. C. Christian, S. Cihangir, J. Fast, R. Kutschke, S. Kwan, M. Marinelli, L. Uplegger, J. Andresen, M. Bowden, G. Cardoso, H. Cease, C. Gingu, J. Hoff, A. Mekkaoui, M. Turqueti, R. Yarema, J. Howell, C. Kendziora, M. Kozlovsky, M. Larwill, C.M. Lei, A. Shenai, A. Toukhtarov, M.L. Wong , S. Austin, S.Jakubowski, R. Jones, G. Sellberg, M. Ruschman

Frascati: S. Bianco, F. Fabbri, M. Caponero, D. Colonna, A. Paolozzi

Iowa: C. Newsom, M. Divoky, J. Morgan

Milano: G. Alimonti, S. Magni, D. Menasce, L. Moroni, D. Pedrini, S. Sala

Syracuse: M. Artuso, C. Boulahouache, J.C. Wang,

Tennessee T. Handler, R.Mitchell, S. Berridge

Wayne State: D. Cinabro, G. Bonvicini, A. Schreiner, A. Guiterrez, G. Gallay, S. LaPointe

- Fermilab: A.A. Hahn, P. Kasper, H. Cease, J. Howell, J. Krider, A. Lee, D. Olis, T. Tope, W. Stuermer, C. Serritella, Z.Shi, D. Butler, B. Pritchard, Y. Orlov
- Frascati: F. Bellucci, M. Bertani, L. Benussi, S. Bianco, M. A. Caponero, F. Fabbri, F. Felli, M. Giardoni, G. Mensitieri, A. La Monaca, E. Pace, M. Pallotta, A. Paolozzi, B. Ortenzi
- Southern Methodist University: T. Coan, M. Hosack
- University of California, Davis: P.Yager
- University of Houston: K. Lau, B. Mayes, G. Xu, Siva Subramania, A. Daniel, M.Ispiryan
- University of Virginia: M. Arenton, S. Conetti, B. Cox, A. Ledovskoy, M.Ronquest, D. Smith, D. Phillips, H. Powell, W. Stephens

Forward Silicon Tracker WBS 1.7

- Colorado University: J.Cumalat, P.Rankin, Eric Erdos
- Fermilab: J. Andresen, G. Cardoso, C. Gingu, J. Hoff, M. Hrycyk, A. Mekkaoui, R. Yarema, J. Andresen, K. Knickerbocker, A. Dyer
- Insubria University: P. Ratcliffe, M. Rovere
- INFN Milano: G. Alimonti, M. Citterio, S. Magni, D. Menasce, L. Moroni, D. Pedrini, S. Sala, S. Erba, P. D'Angelo, S. Latorre, M.Malatesta
- INFN Pavia: G.E. Cossali, P.F. Manfredi, M. Manghisoni, M. Marengo, L. Ratti, V. Re, M. Santini, V. Speziali , D. Di Pietro, G. Traversi , K. Fisher, L. D'Angelo

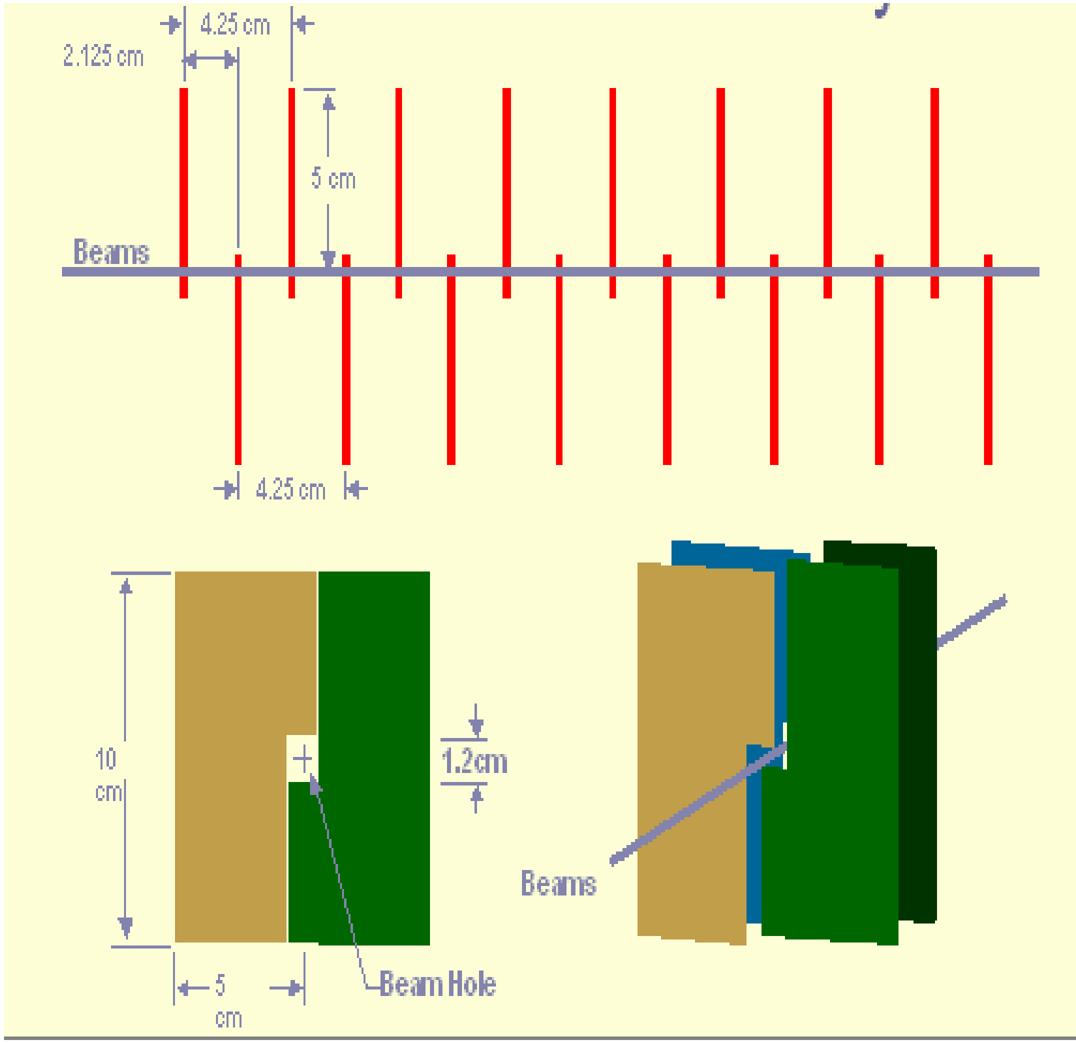
Pixel Vertex Detector

Reasons for Pixel Detector:

- Superior signal to noise
- Radiation Hard
- Excellent spatial resolution: <9 μm depending on angle
- Pattern recognition power
- Very low occupancy

Special features:

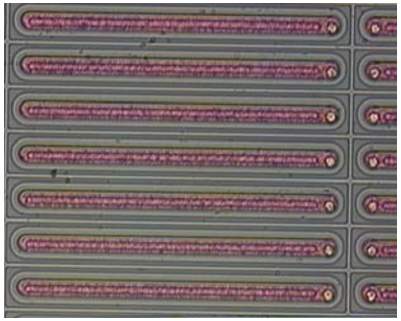
- Info used directly in the L1 trigger.
- Placed inside a dipole and gives standalone momentum measurement.
- Sitting close to beam and in vacuum
- 30 stations with 23 million pixels in total
- Total length ~1.3m



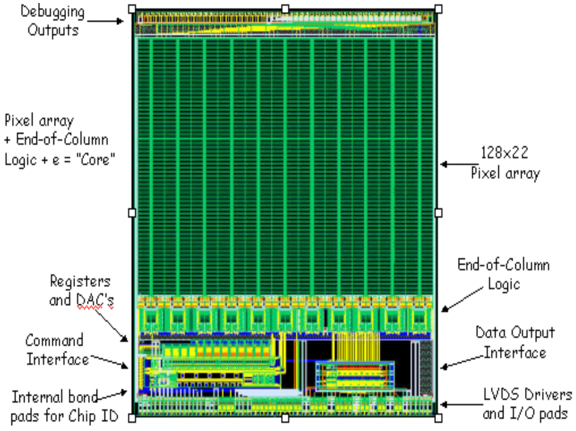
Pixel Detector

- Pixel Sensor bump-bonded to Readout chip
- Fine segmentation
  - 50 μm x 400 μm
  - Large number of channels
  - Electronics in the active tracking volume
  - High power density
  - Material budget
- Basic building block – Multichip Module (MCM)
  - Large amount of data
  - Large number of HDI and cables
- Assemble modules on substrate to form pixel half station

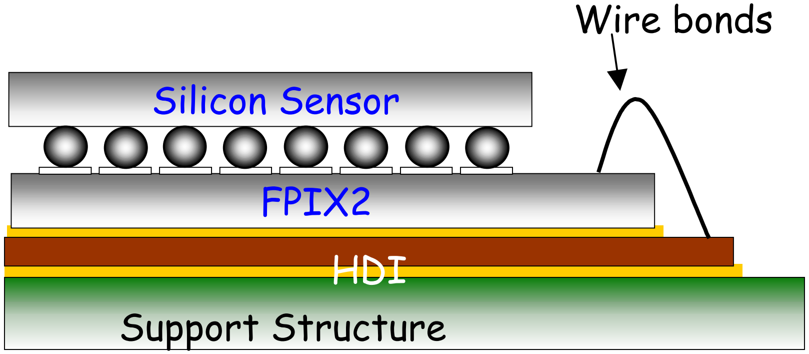
Si pixel sensors



Pixel Readout chip



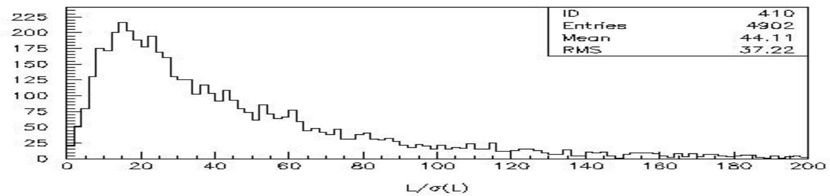
Multichip module



BTeV Pixel Vertex Detector Properties

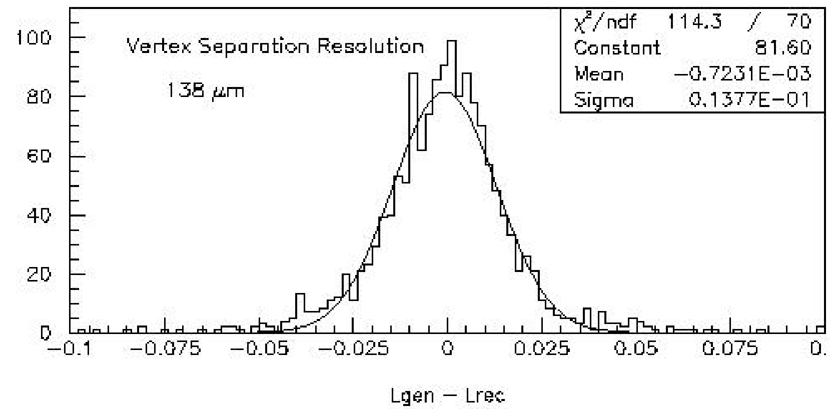
Property	Value
Pixel Size	50 μm x 400 μm
Outer plane dimension	10 cm x 10 cm
Central square hole (adjustable)	Nominal setting: 12mm x 12mm
Total number of planes	60
Total number of stations	30
Total number of pixels	23 million
Total Silicon active area	0.5 m^2
Separation of stations	4.25 cm
Pixel plane orientations (per station)	One with narrow pixel dimension vertical and the other with narrow dimension horizontal

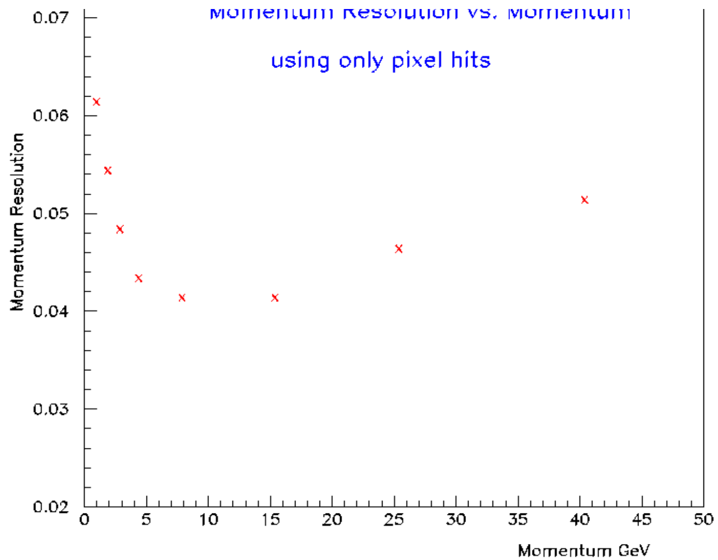
Physics Performance ($B_s \to D_s K^+$)



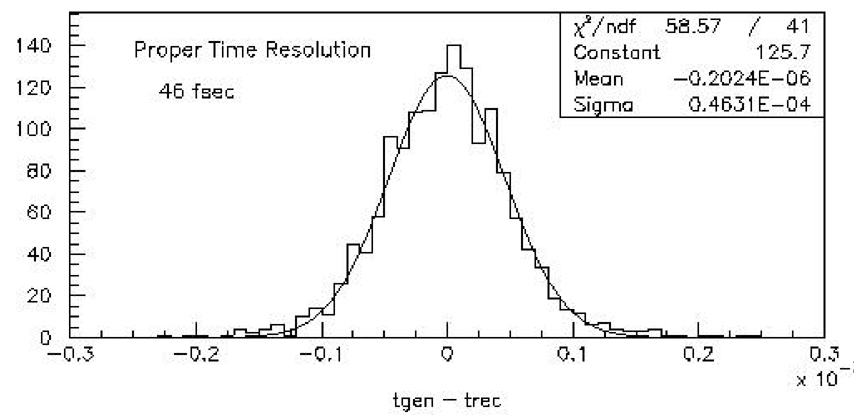
Distribution in L/s of Reconstr .B_s

Primary-secondary vertex separation
Reconst - generated. $\sigma = 138\mu$





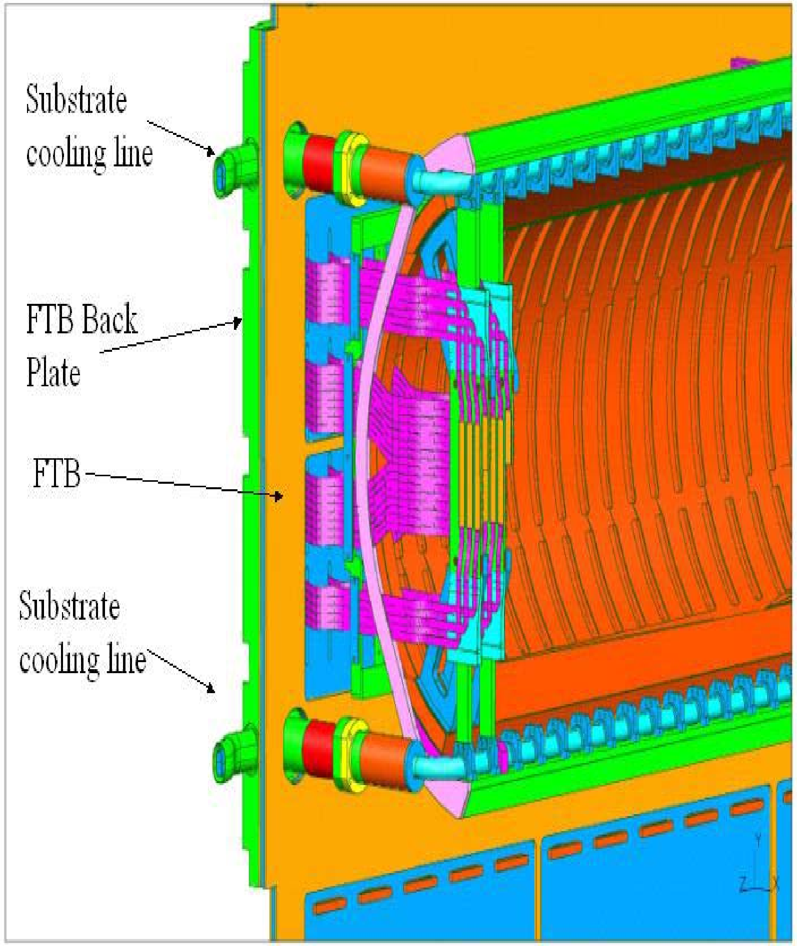
Momentum Resolution



τ_{proper} (reconstructed) - τ_{proper} (generated)
$\sigma = 46$ fsec

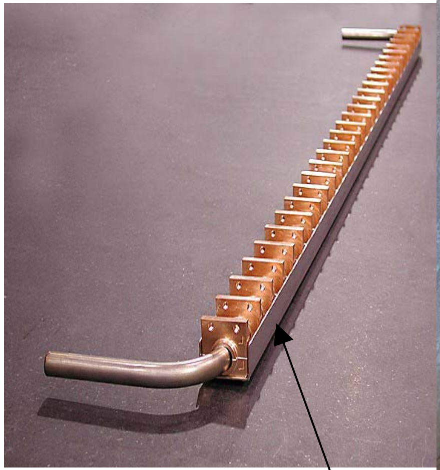
Pixel R&D: Substrate and Cooling

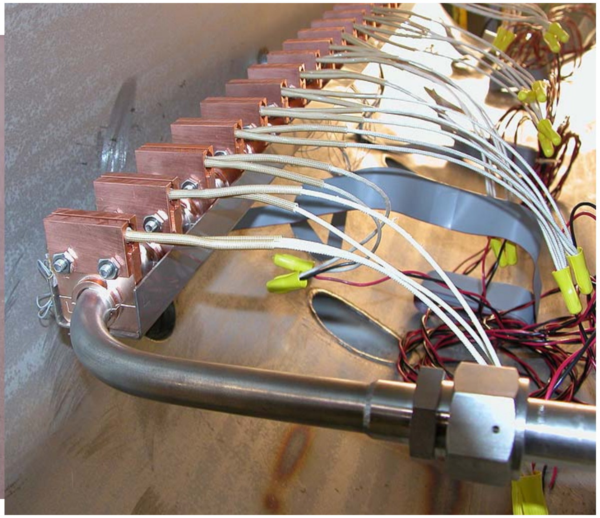
- Temple '02: leak-tight joint in vacuum
- Our solution and RD effort:
  - No coolant-vacuum joint design
  - Use high thermal conductivity Thermal Pyrolytic Graphite (TPG) as substrate; heat removed by conduction
  - Use cryogenic source as heat sink
- Temple '03 Recommendations:
  - Demonstrate the robustness of the proposed design in the case of failure of cooling
  - Consider increasing contingency on multicomponent systems to reflect uncertainties or risks not present at the single-component stage



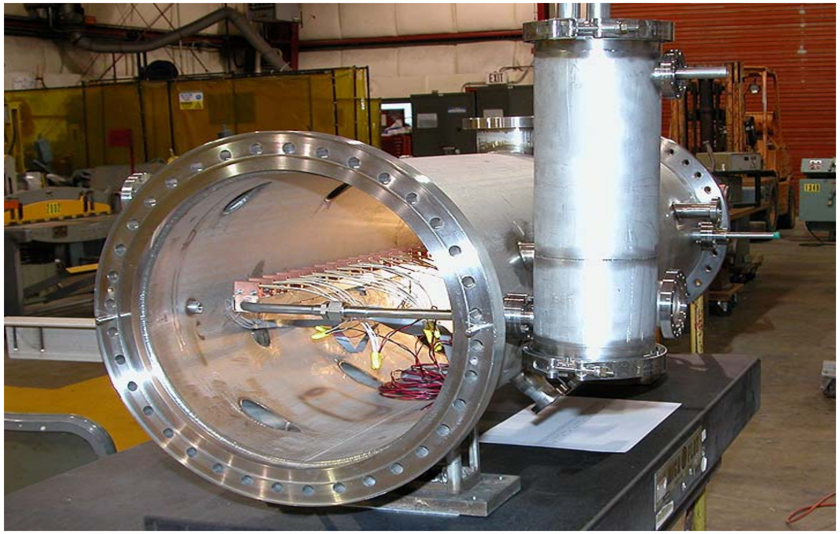
FTB : feed-through board

Cold Block Assembly Test





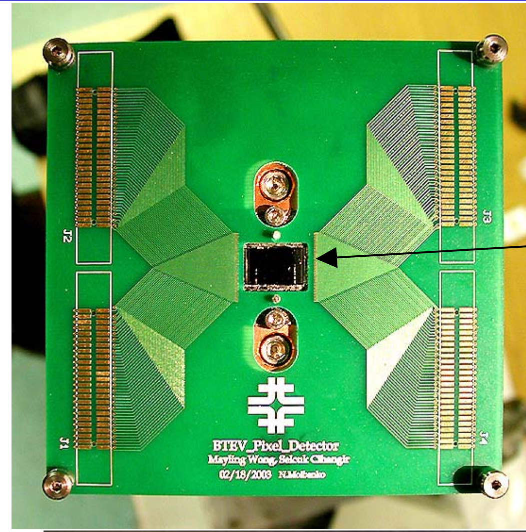
30 Cu tabs brazed to full size SS tube



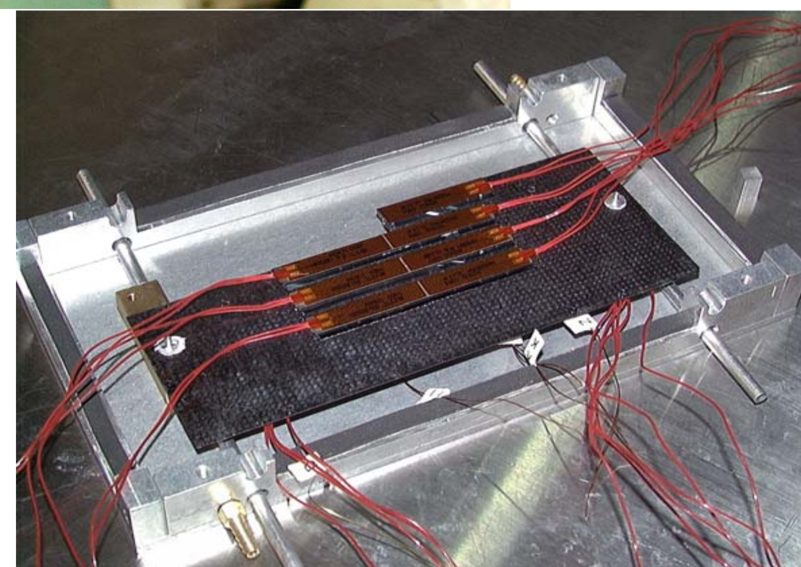
- Test setup:
  - Heaters on tabs – simulate pixels
  - Thermistors on tube and tabs
- Measure temperature gradient between ends and compare to FEA
- Test system limitation:
  - Decrease LN_2 flow
  - Increase heat load
- Measure vibration
- Status: preparing for the test

What will happen if temperature control system fails?

- **Tests ongoing**
  - **Bump-bond thermal test**
    - Thermal cycle of bump-bonded dummies from -25C to room temperature – little effect
    - Test of bump-bonded dummies down to cryo-temp : prelim results (low statistics) show no bad channels
  - **Dummy Silicon modules with heaters placed on TPG and with two ends fixed at -30C**
    - Check thermal profile without/with heaters on
    - Check thermal profile by turning off heaters randomly
    - Test thermal cycle effects on position of modules (any displacement)
- **Prototype temperature control elements (heaters/RTD) tests now under preparation**
- **Preliminary failure mode analysis**



Bump bonded hybrid glued to TPG & mounted on a PCB; placed in cryo system

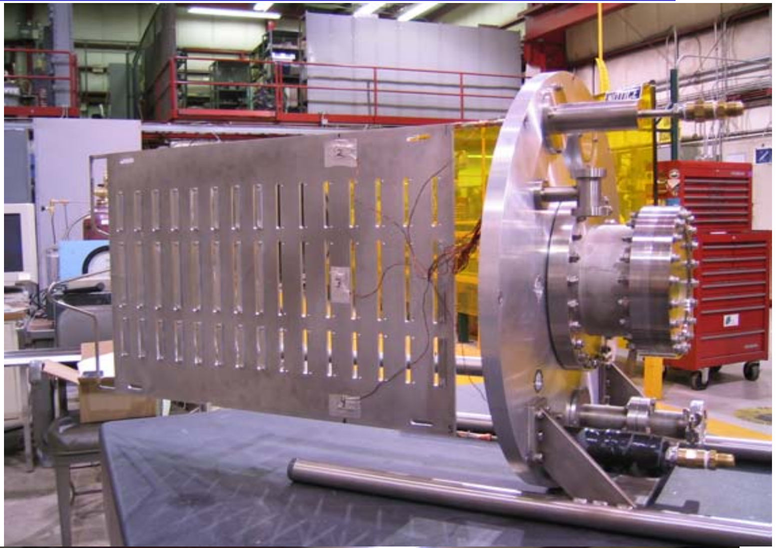


Vacuum System

- Temple '03: Ensure the detector can meet BD vacuum requirements
- **BD review (Oct 2003) : Overall design**
  - No issues in principle
  - Regeneration frequency needs to be defined and assessed
- **Study possible failure scenarios and how to mitigate these.**
- **Design has made good progress within the last 6 months:**
  - Full layout of the vacuum system, transfer lines, and controls
  - LN_2 - cooled water pump design very advanced
  - Design of a LHe cryopump that can be prototyped
  - Details on pump-down and regeneration procedures
- **Outgassing test and RGA scan on FTB and substrate material (TPG) performed (recommendation of BD review)**
- **Full-size FTB prototype in fabrication; this will be used in the System Demonstrator test (plan for 2005)**
  - Test real pixel half-planes in vacuum and with prototype cooling and temperature control systems
  - Gas load measurement using this model
  - Test different operation and failure modes

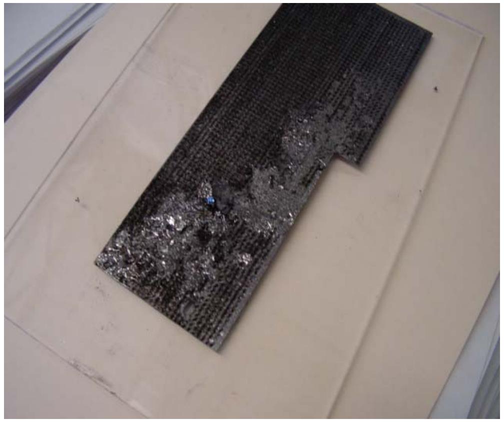
Loaded Cryopanel Test

- Study pumping capacity of the cryopanel as function of time as water molecules condensed on the surface
- Determine how much time in between regeneration
- Loaded cryopump test results:
  - Simulated > 300 days of operation (> 42 weeks)
  - Equivalent 100 μm thick ice layer
  - Limit of test due to LN2 supply running out – cyropanel pumping is not slowing down
- Expected pumping speed is enough to bring vacuum pressure ~ 1.5 x 10^{-8} torr



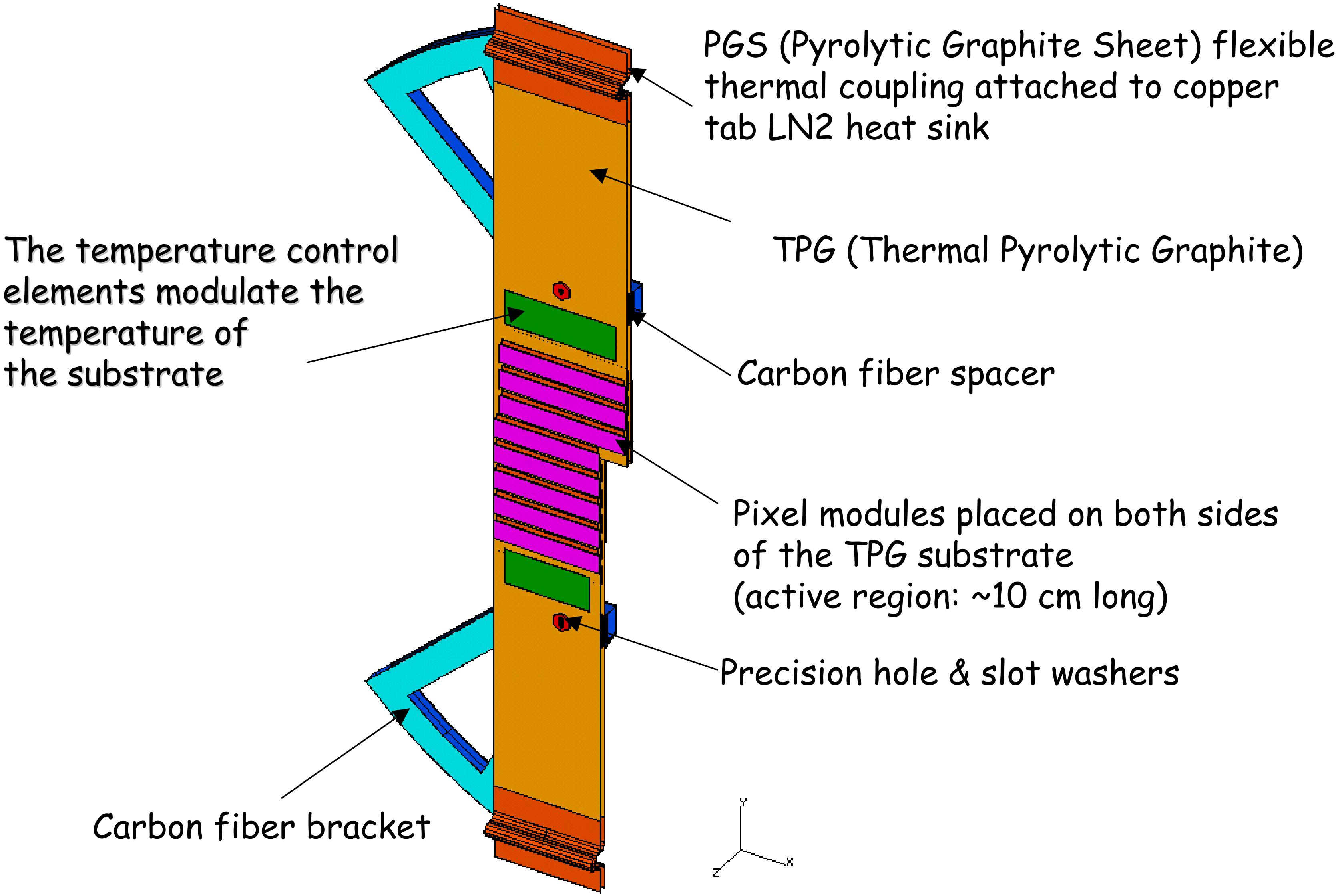
Thermal Pyrolytic Graphite (TPG)

- Need to stiffen TPG substrate (delamination)
- Parts got damaged easily
- Too many handling and shipping steps
- Need to do the strengthening without adding a lot of material while keeping a reasonable thermal performance.

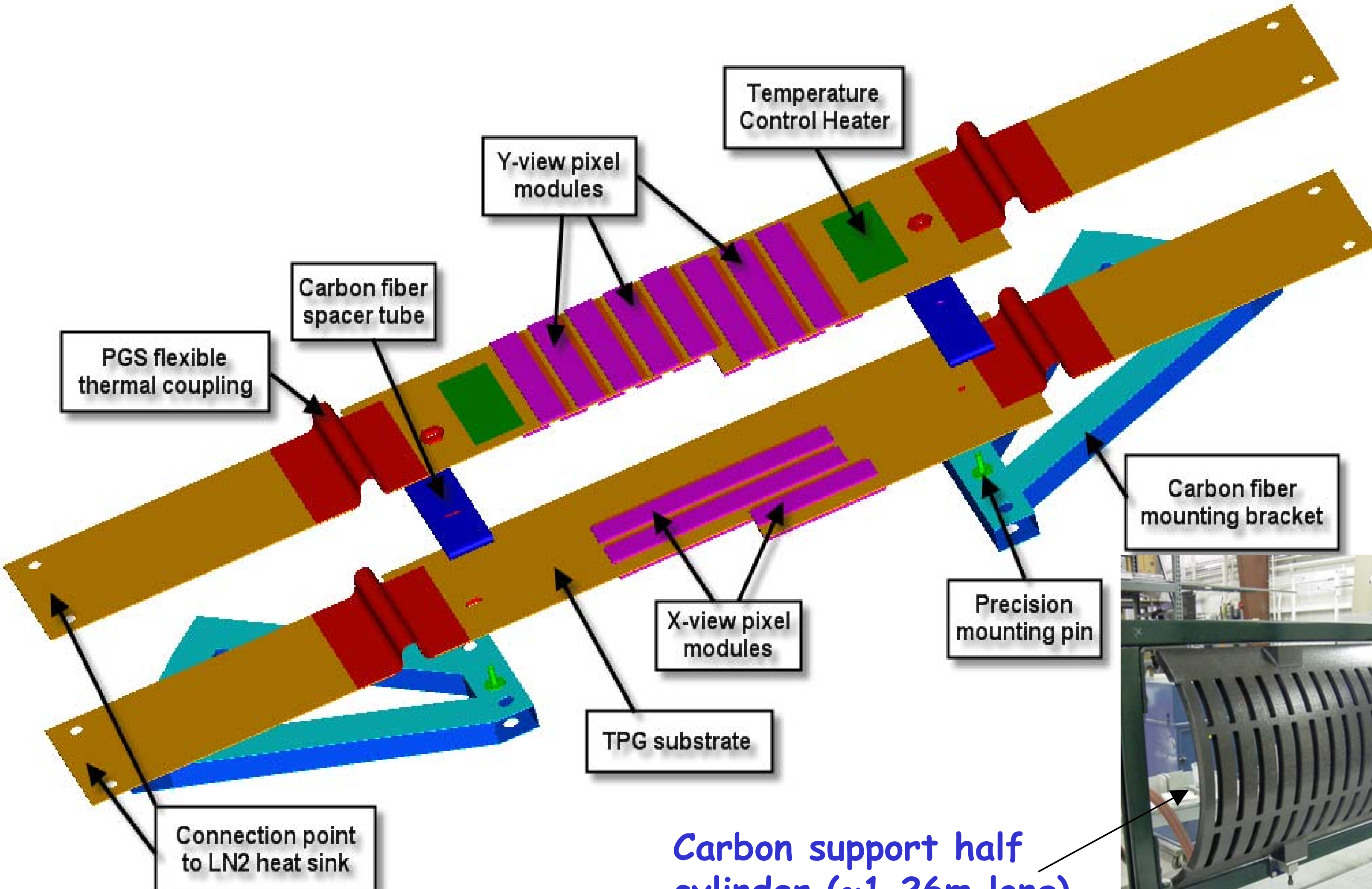


- Drill a pattern of holes on the surface
- Add one ply of Carbon Fiber Reinforced Plastic (CFRP) on TPG as facing sheet.
  - Carbon fiber is thermally and electrically conductive
- Can be done in Lab 3 (loads of experience and equipment)
- Will glue the Pyrolytic Graphite Sheet on the TPG and then do the CFRP lamination

Technical Design
Pixel Half-Plane

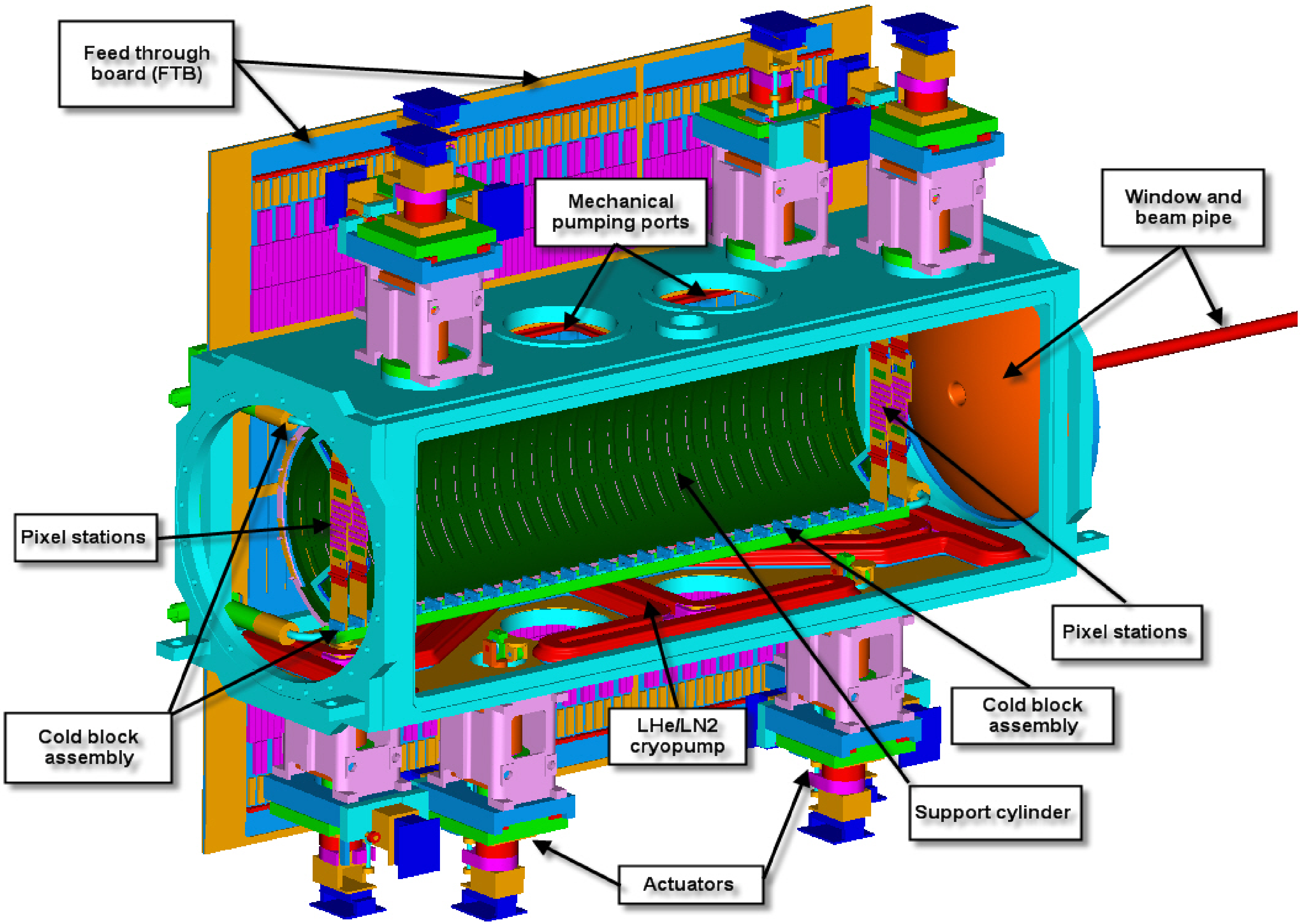


Pixel Half-Station



Carbon support half cylinder (~1.26m long)

Pixel Detector Assembly



Baseline Design of the Forward Tracker

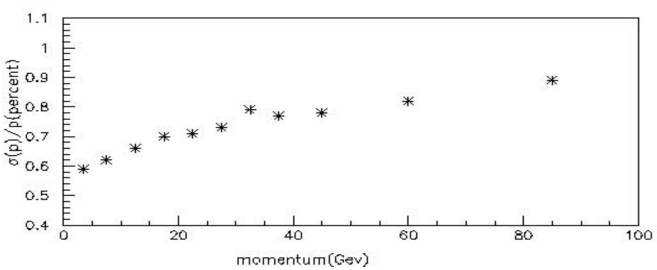
- High density of tracks in the forward direction
- Straws chosen because of small cell size (segmentation)
- Track density near beam requires even higher granularity -> Silicon microstrip detectors
- Both are conservative technologies; profit from experience of CDF/D0 and LHC experiments

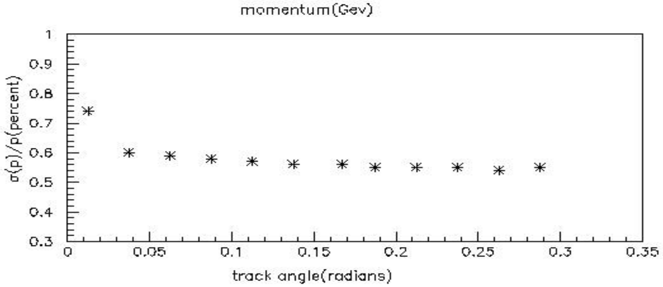
Forward Tracker

- **Straws: uses Atlas design as basis**
- **Silicon Strips: simple single sided p⁺/n design**
- **Expected performance: Momentum resolution better than 1% over full momentum and angle range**

Straw size	4 mm, 8mm diameter
Central dead region	26 cm x 26 cm
Number of Stations	7
Z positions (cm)	96, 138, 196, 288, 332, 382, 725
Active Half size (cm)	27.2, 40.8, 61.2, 88.4, 102, 115.6, 197.2
Views per station	3
Layers per view	3
Total number of straws	26784
Total station thickness	0.8% X_0
Total channels	53568
Readout	ASDQ + TDC(8 bits), sparsified

Straws at large angles (low occupancy)



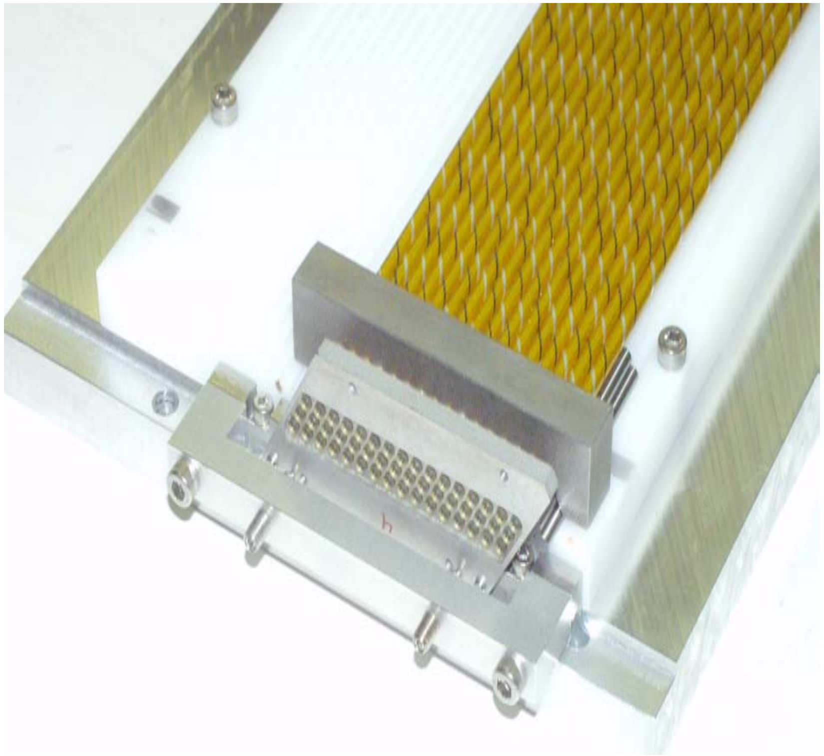


Property	Value
Silicon Sensors	$\sim 7.9 \times 7.9\ cm^2$, p-on-n type
Pitch	100 μm
Thickness	320 μm
Sensor configuration	4 ladders with 4 sensors each
Coverage	$30.6 \times 31.6\ cm^2$
Central Hole	$5.4 \times 5.4\ cm^2$ ($7 \times 7\ cm^2$ for last station)
Total Stations	7
Z Positions	85.5, 127.5, 185.5, 277.5, 321.5, 371.5, 714.5
Views per Station	3 (X,U,V)
Channels per view	6,144
Total Channels	129,024
Readout	Sparsified Binary

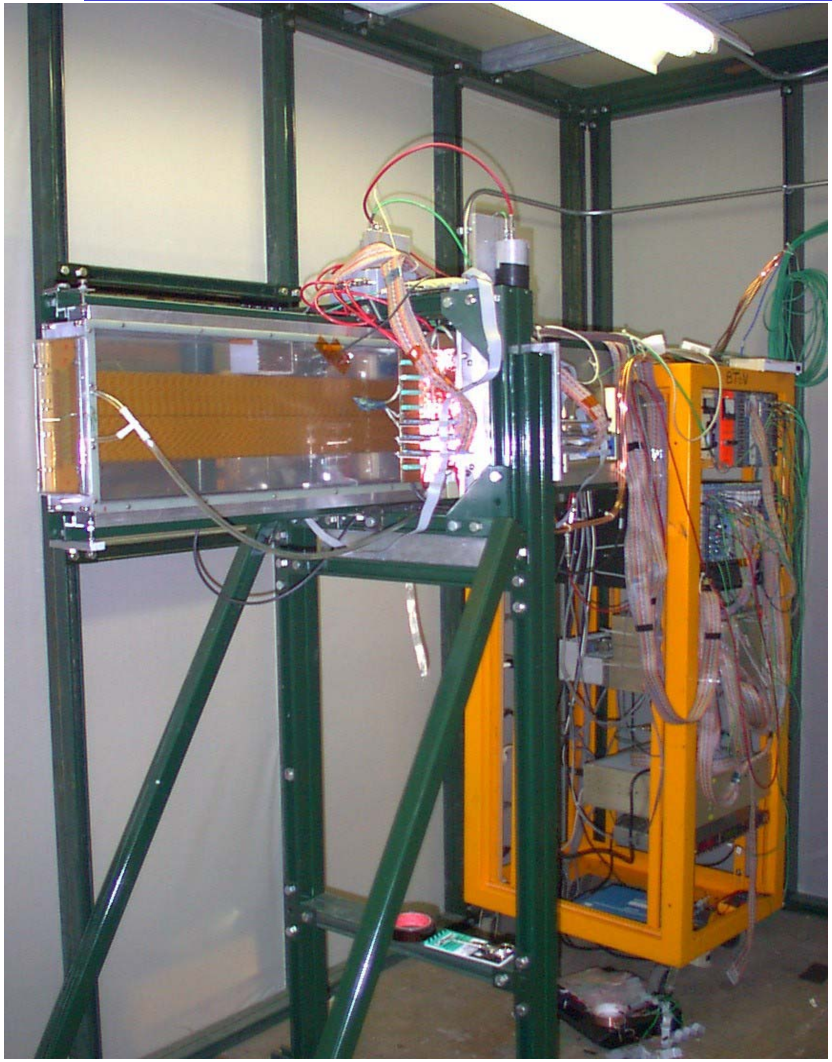
Strips at small angles (high occupancy)

Forward Straw Tracker Characteristics

- Low mass (0.8% average radiation length/Station) to minimize scattering.
- Tracking resolution (150 mm per view) adequate for momentum resolution
- High efficiency(~95% per plane) to detect tracks
- Assembled in groups of 48 straws - modules

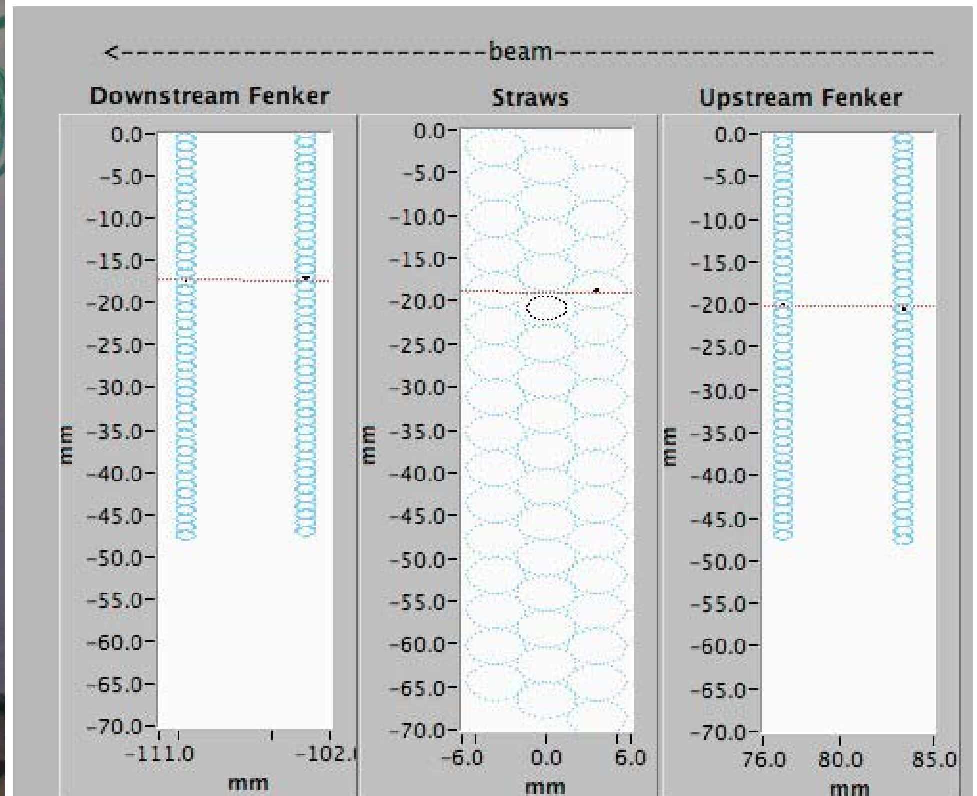


Straw Detector – Test Beam



Straw prototype in test beam

Temple '03: "Continue prototype tests with Cosmics and in test beam; involve outside institutions"



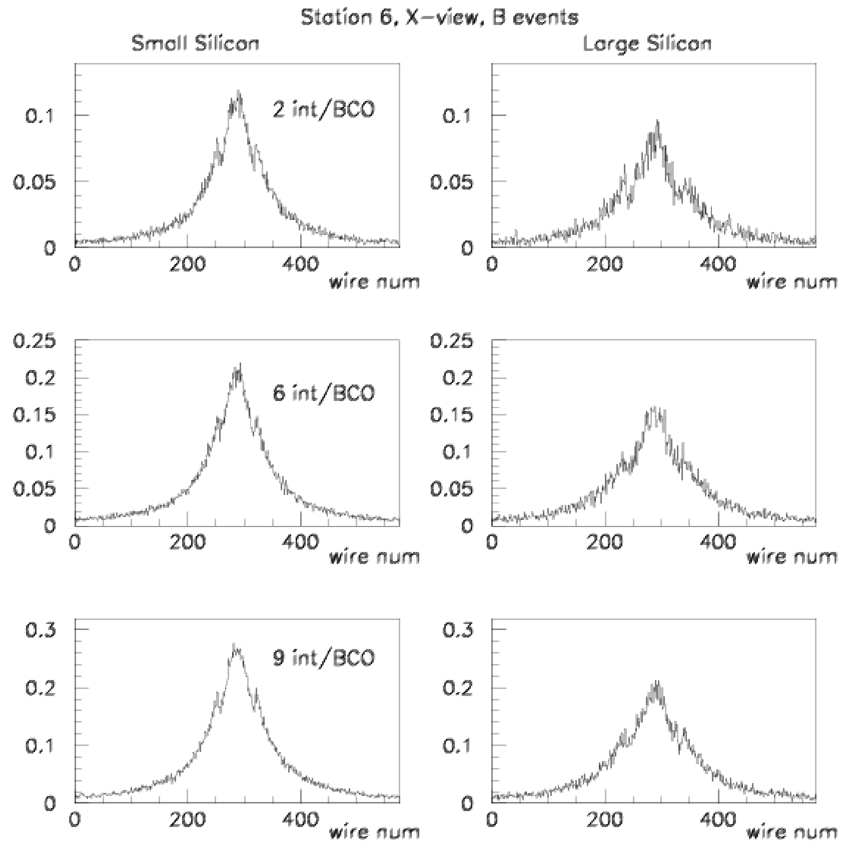
Event display – straw prototype and wire chambers

Straw Detector – Occupancy Studies

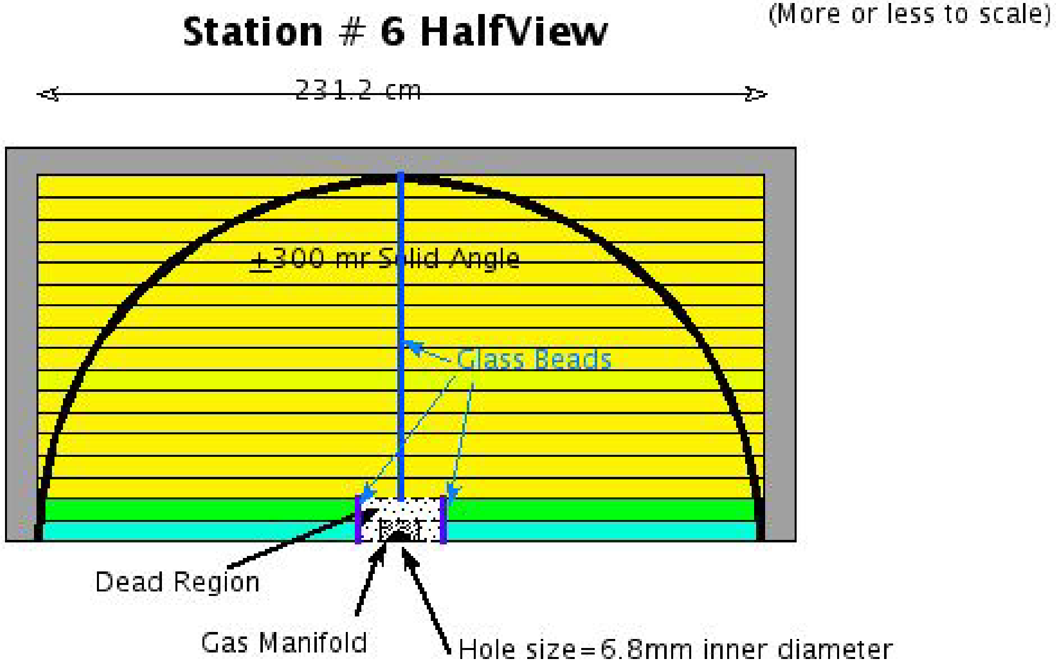
Do we need to increase size of Forward Silicon for 396 nsec bunch crossings? Temple 2003 Recommendation

Baseline 27x27cm^2
Option 40x40 cm^2
Occupancy reduced by ~25%

Tracking efficiency:
pixel-seeded tracks – efficiency drops from 98% at 2ints/BX to 95% at 9 ints/BX but no improvement with larger silicon.
tracks without pixel hits – no improvement in efficiency, but only half as many ghost tracks with larger silicon.
-> Keep Baseline size 27x27 cm



Straw Detector - "half-view"



17 modules/HalfView
Mod type 1=96 straws (short straw)
Mod type 2=48 straws
Mod type 3=720 straws

total=864 straws

Mod type 1 (96 4mm diameter Straws, gas Manifold and 27 cm dead region)

Mod type 2 (48 4mm diameter Straws, 27 cm dead region)

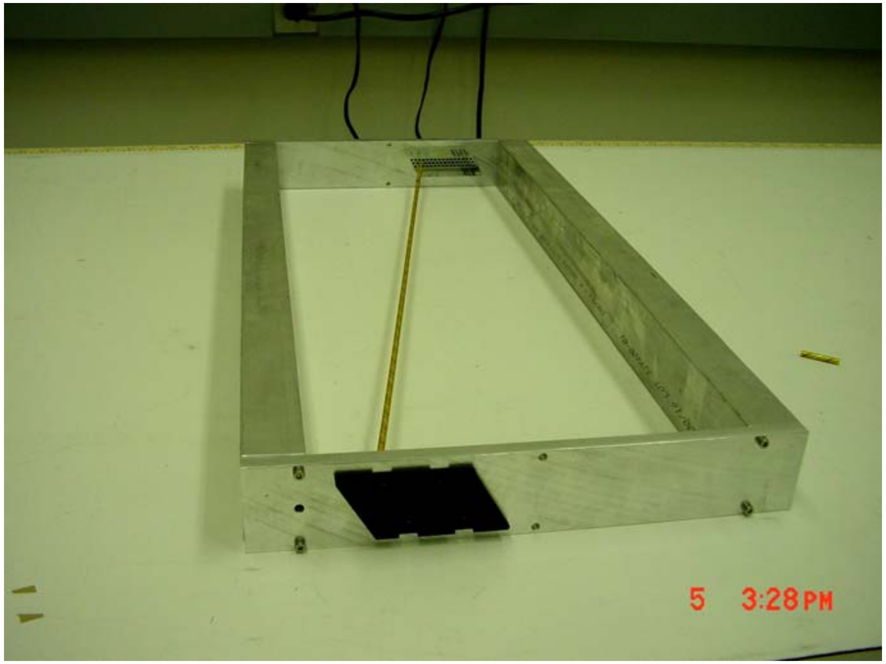
Mod type 3 (48 4mm diameter Straws)

4mm modules have 3 planes of 16 straws

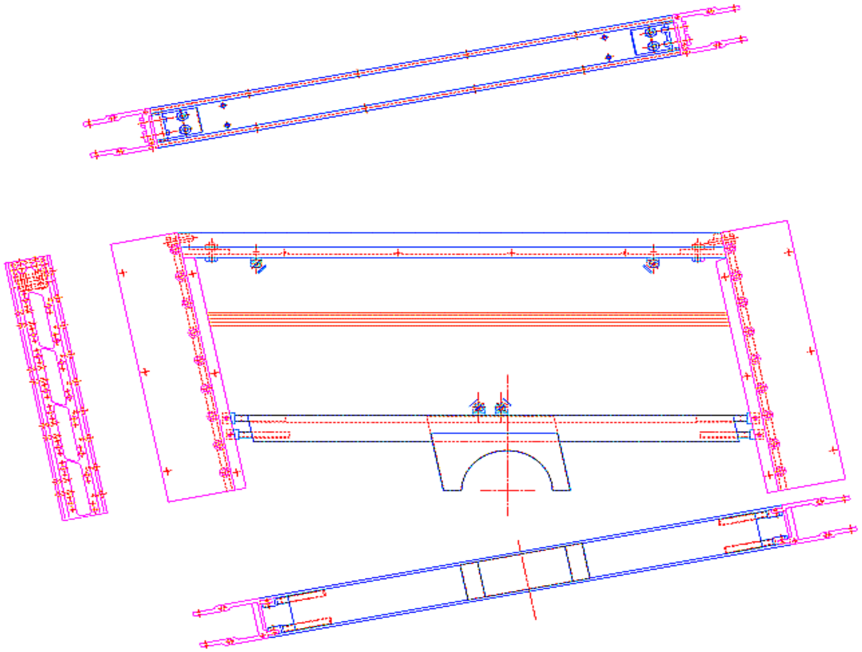
module is 6.8cm high (6.4 mm straws+2mm gap each side)

Straw Detector Prototype

Straw Length =54 cm
384 Straws/View
1152 Straws/station

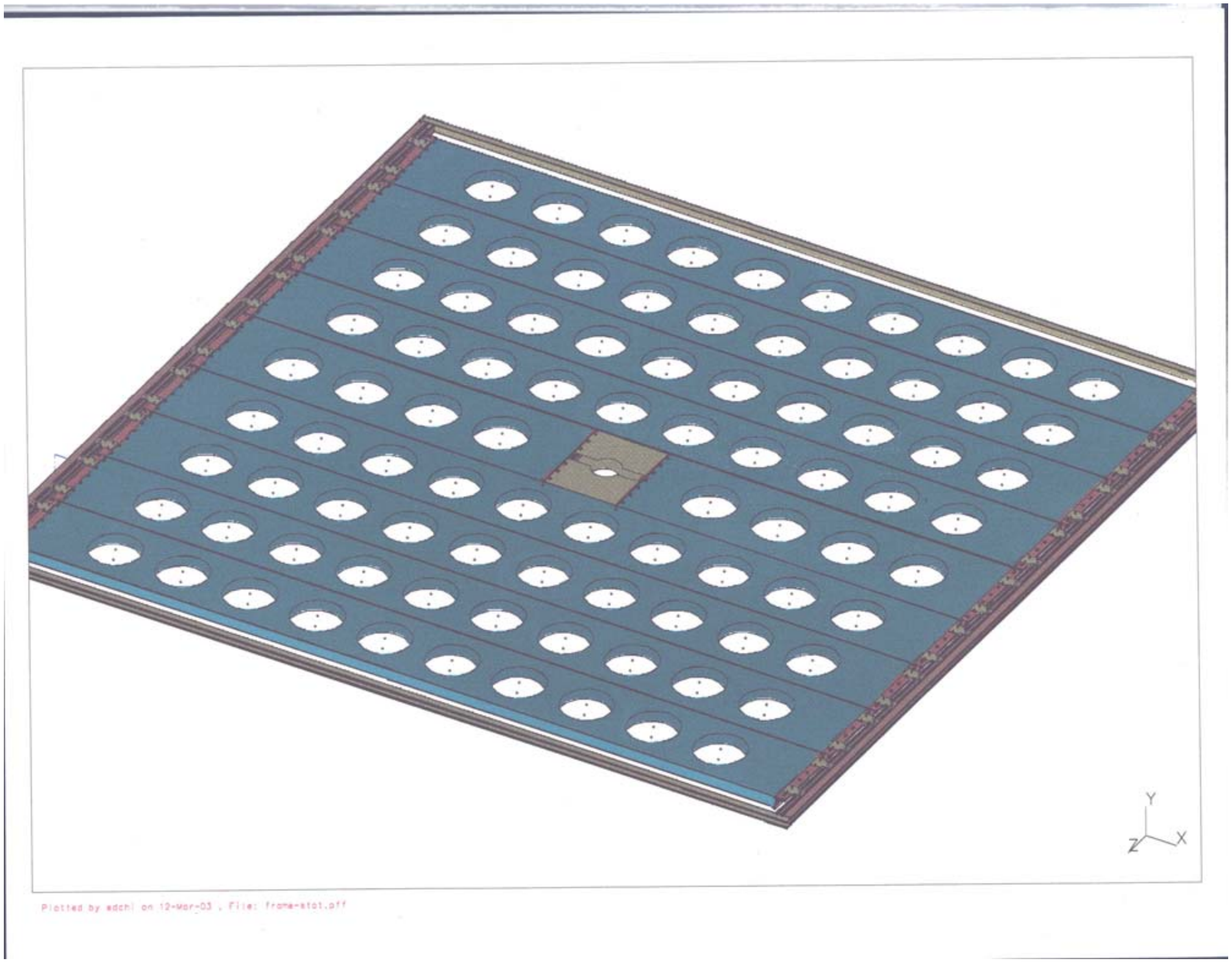


Station 1 “Prototype” Frame



Station #1 U,V HalfView Frame.
X View is simple rectangular shape

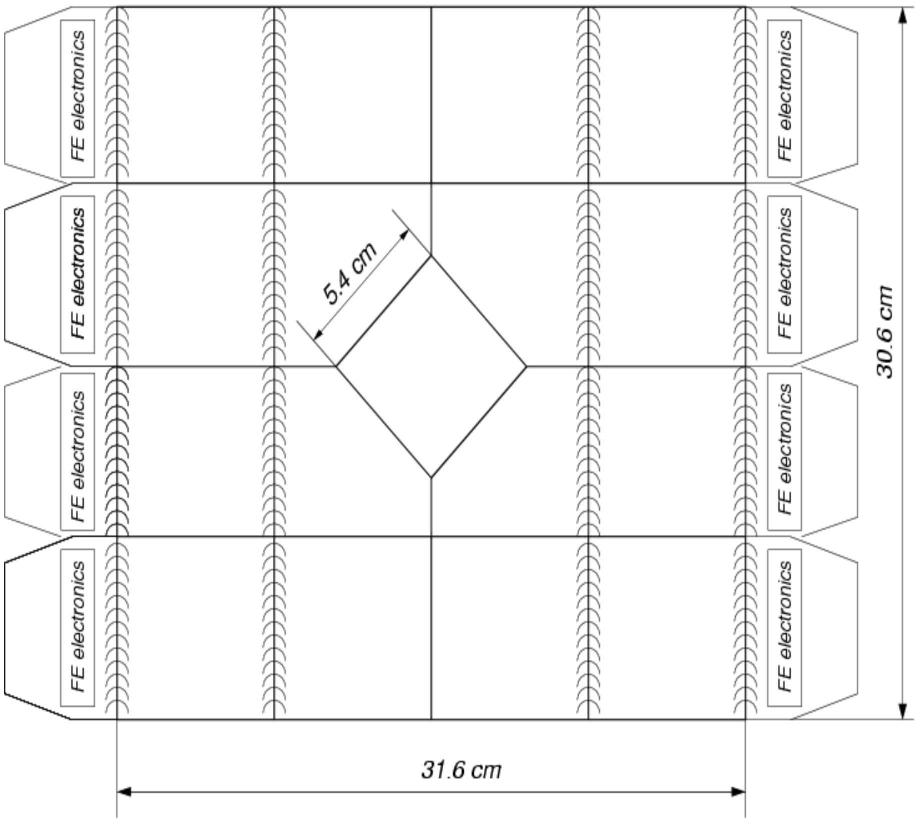
Straw Detector Station 7



Station 7 View constructed of “SuperModules”

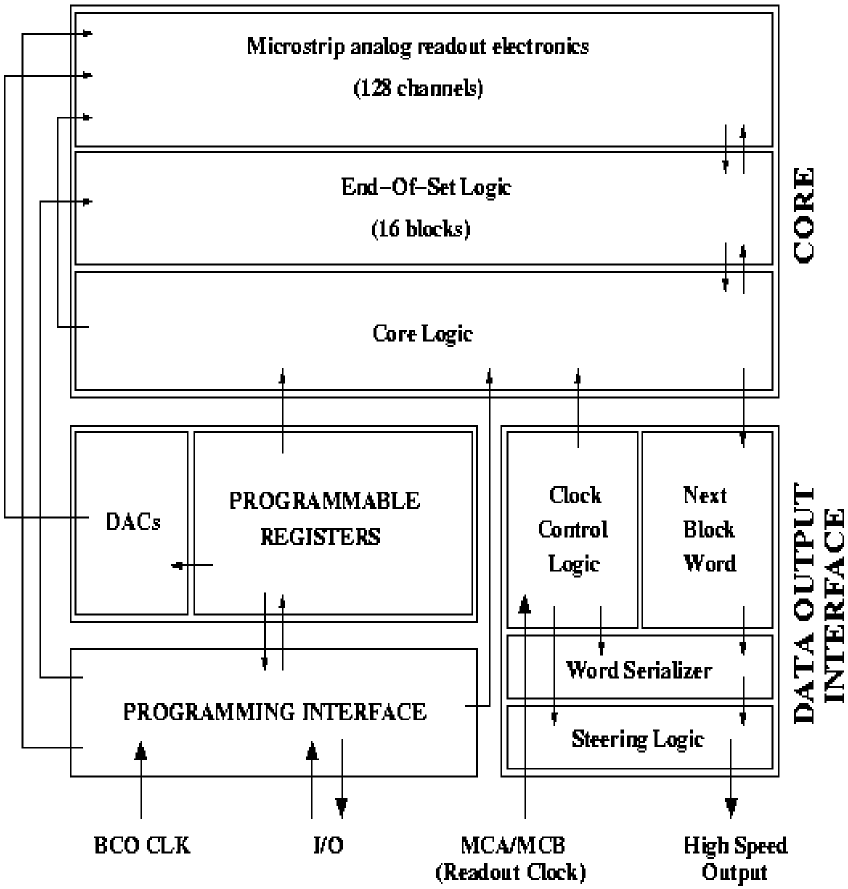
Baseline Silicon Tracker Design

- 7 stations
  - 3 in dipole fringe field
  - 3 before RICH
  - 1 after RICH
- Coverage from beam pipe to ±15.5cm from the beam
- Each station has 3 planes of 320 μm thick SMD with 100 μm pitch
- Each detector is 7.9 cm x 7.9 cm
- Four detectors form one ladder with readout at both ends



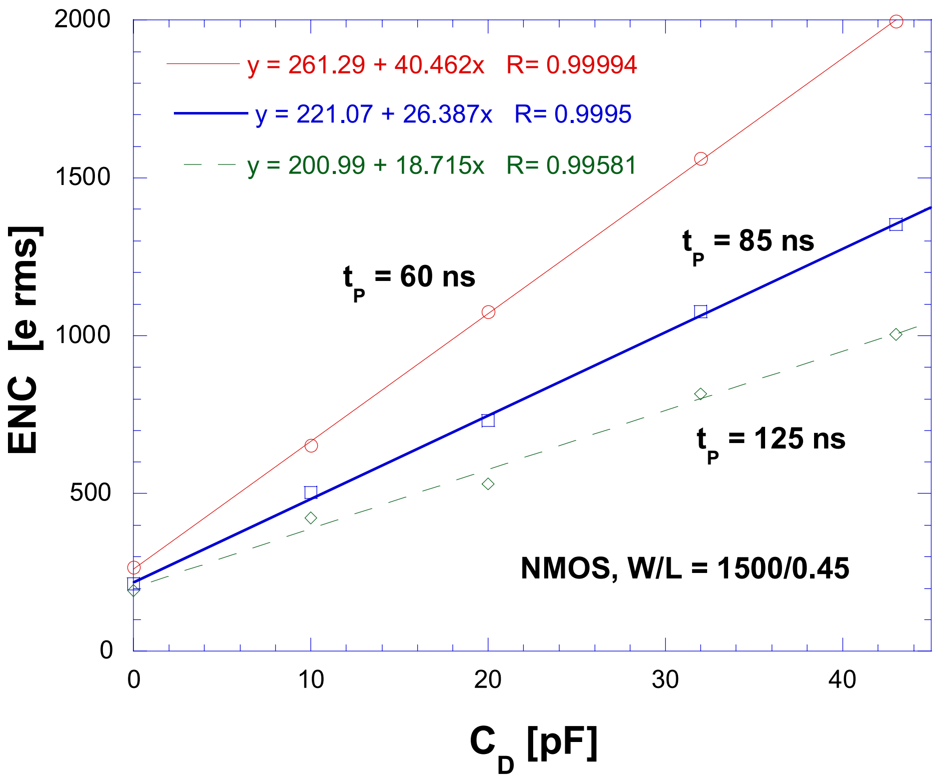
Silicon Strip Readout Chip (FSSR)

- **Temple '02: no effort on FE chip**
- Reported in Temple '03:
  - New silicon strip readout chip using 0.25 μm CMOS process
  - Collaboration between Pavia & FNAL
  - 4 logic sections and architecture identical to FPIX pixel ROC
  - 128 channels arranged into 16 sets of 8 strips
  - 40 prototype chips delivered
- **Temple '03: increase safety margin in the schedule for final FE chip development**
  - Implemented several versions of the analog channel. Best solution to be chosen based on tests
  - Plan to submit another prototype with full functionality of the final readout chip this year



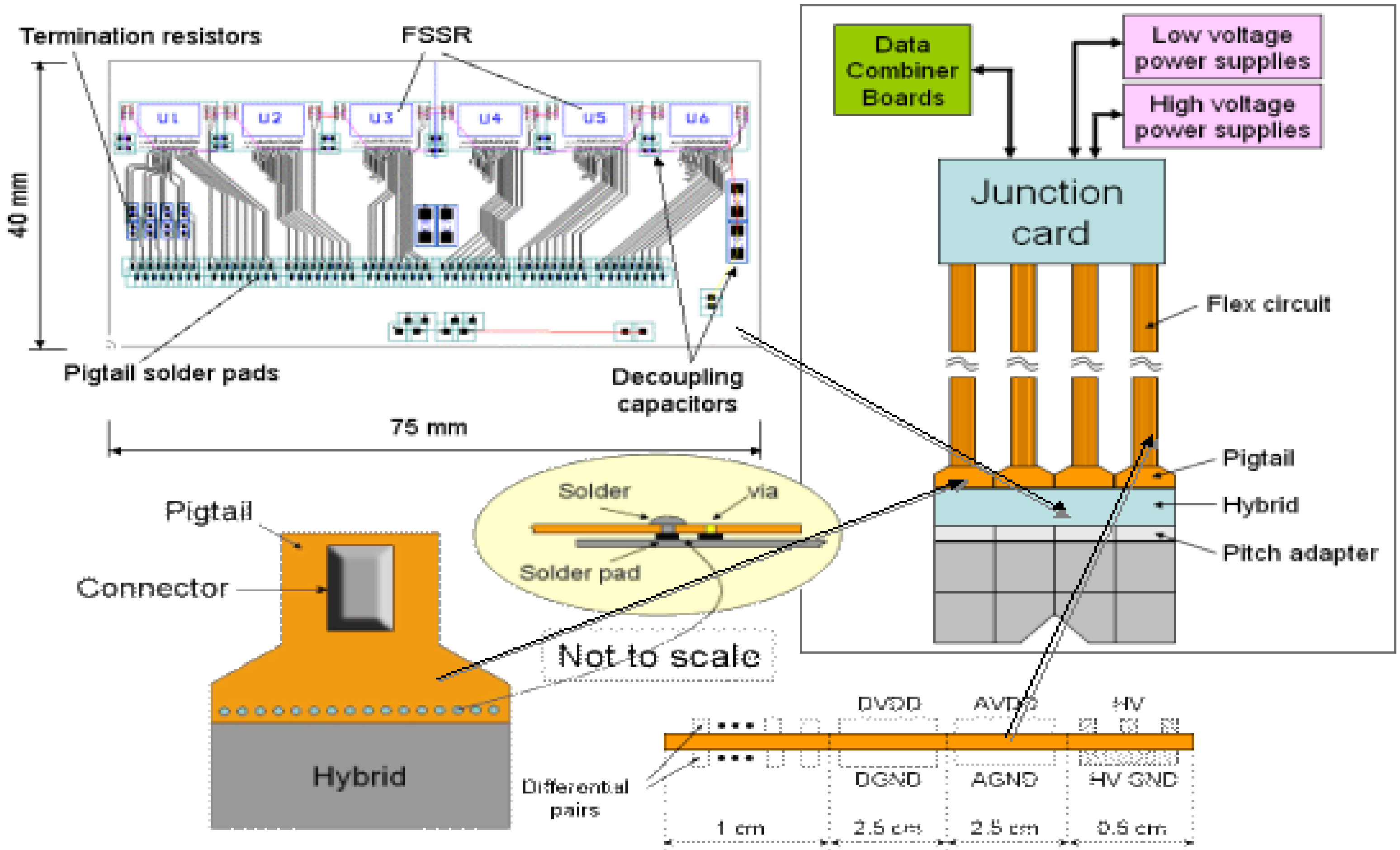
Prototype FSSR test results

- The prototype is fully functional. The behavior of the analog section is in very good agreement with simulations, and noise performance is inside the specs.

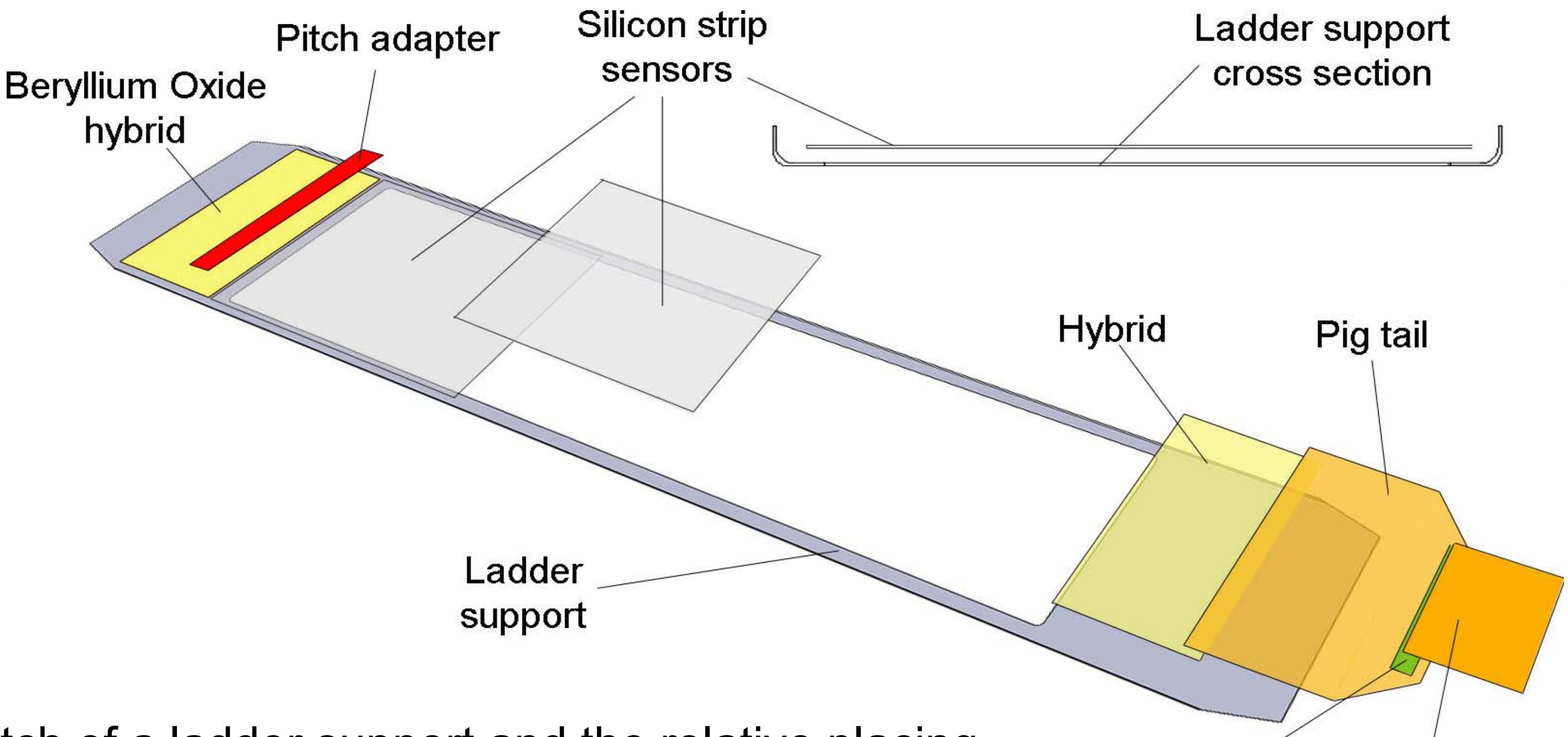


Silicon Strip Readout Electronics

Temple 2003: Start a.s.a.p. the design of the FE hybrid to test performance of the module ….

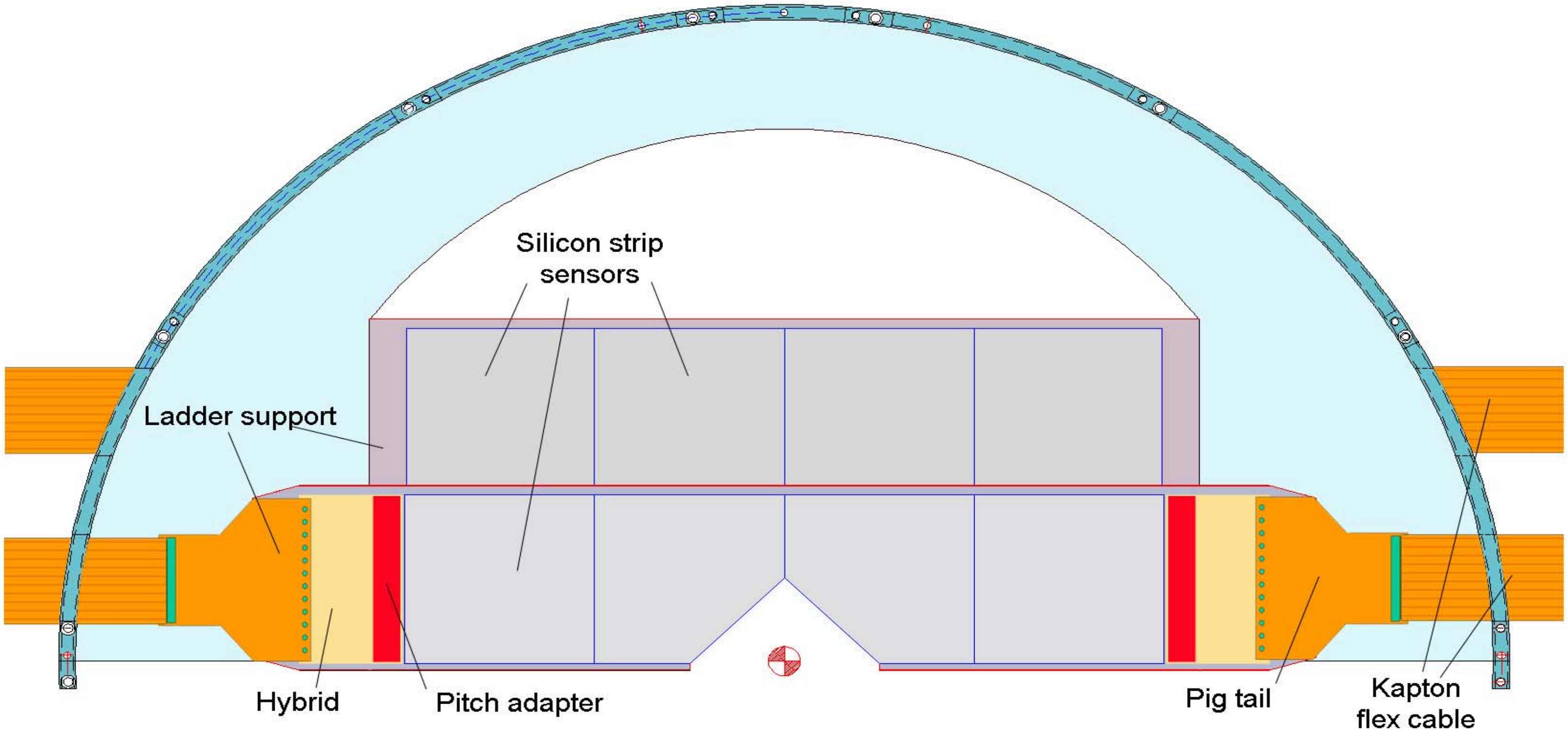


Silicon Strip Detector Ladder Support



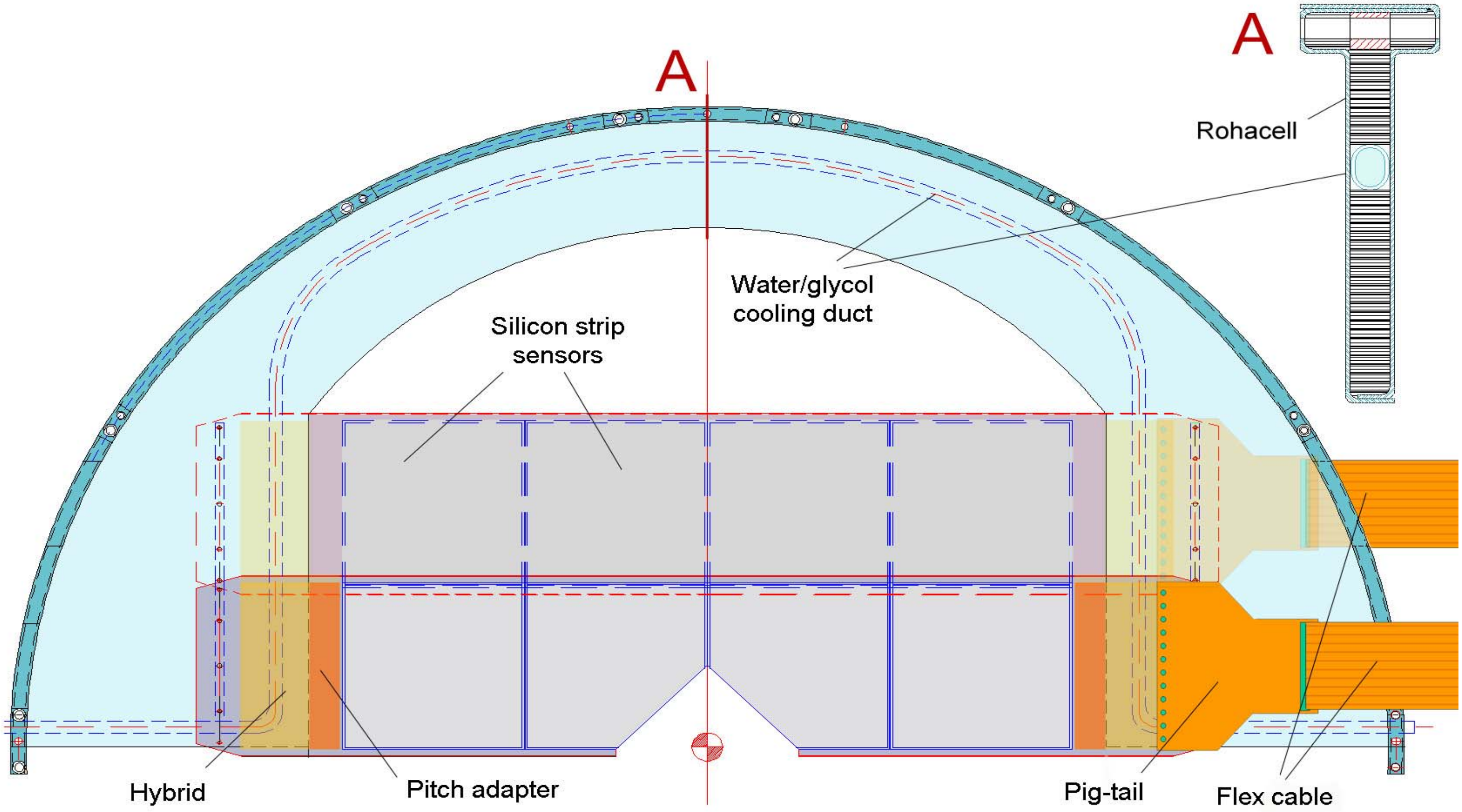
Sketch of a ladder support and the relative placing of silicon strip sensors, hybrid circuit, pig-tail fan-out and kapton flex cable.

Si Strip Detector Support Structure



Sketch of the micro-strip support showing the organization of flex-cables, which cross the structure through dedicated slots.

Silicon Strip Detector
Half Plane Support



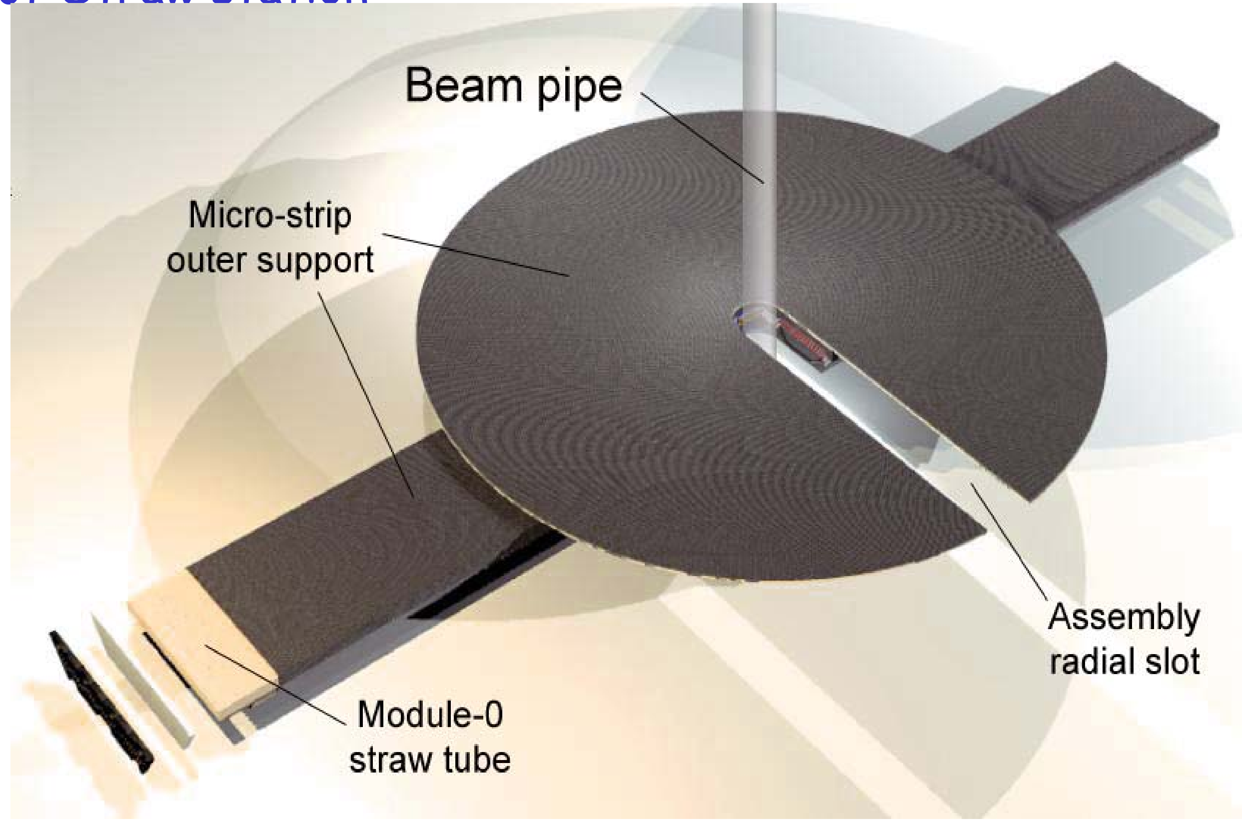
Straw MOX module – Silicon Support

Temple '03: Produce technical designs of the overall mechanical structure & define the interface regions with the beam pipe and Straw Tracker

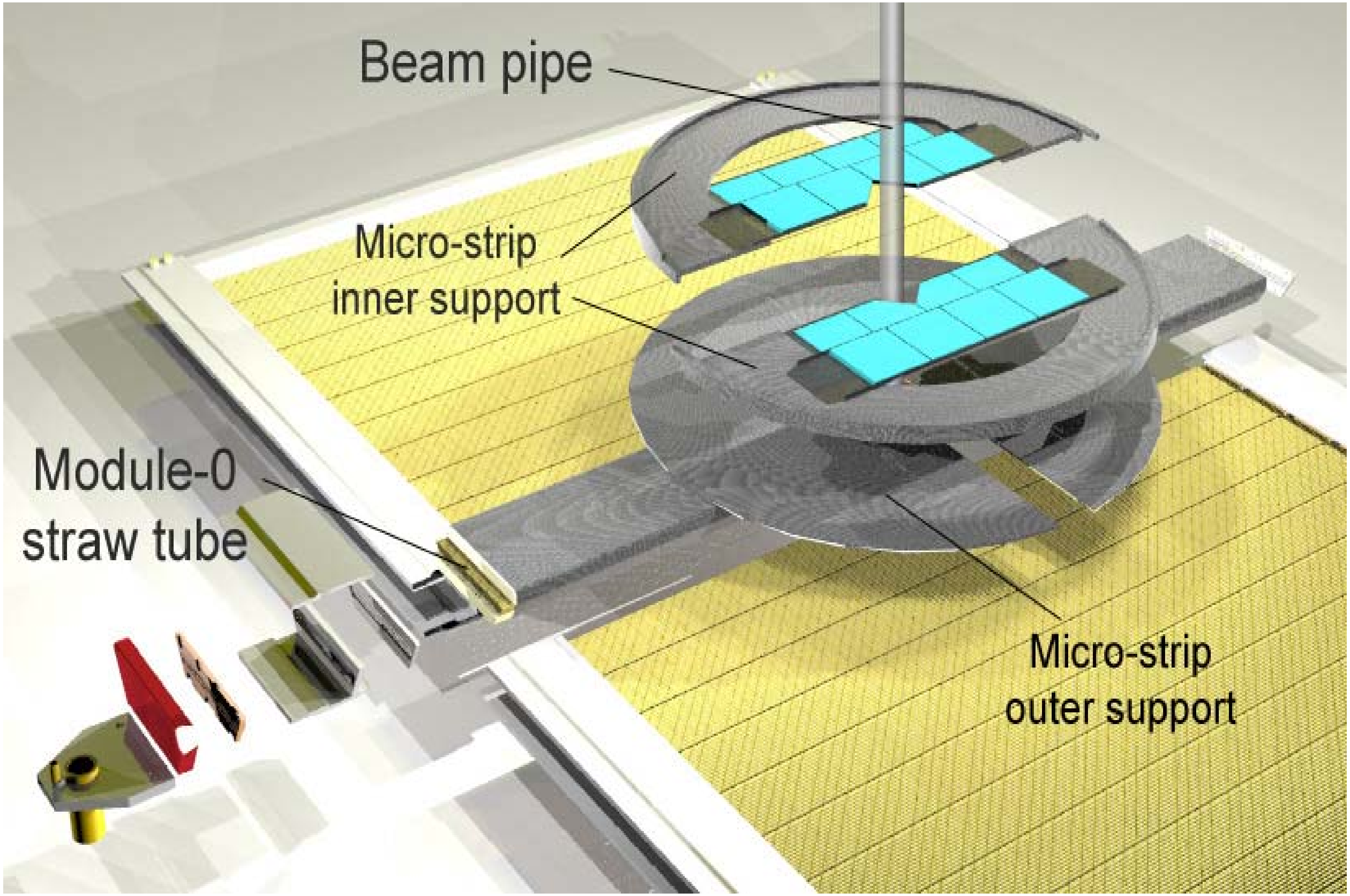
New Straw module designed at Frascati to support the forward Silicon stations. Replaces the 2 modules in X-view that surround the beam-pipe. Supported independently of Straw station

Straws are embedded in rohacell so no tension needed to keep them straight. Module has carbon fiber shell.

Carbon fiber disk is attached for Silicon support



Forward Tracker Station Assembly



Resource Loaded Schedule

- For the last 3 years, each sub-detector has put in a lot of effort into producing a detailed WBS
- Helps to understand the task and provides a fully resource-loaded base cost and schedule
- Cost profiles (total, material, and labor), and contingency
- Milestones established
- High Level Linkage between sub-detector tasks
- Cost book (basis of estimate, vendor budgetary estimates, previous PO etc)
- Risk and critical path analyses

Base Cost and Contingency

Item	M&S (M$)	Labor (M$)	Base (M$)	Contingency (M$)	Total (M$)
Pixel	8.05	7.45	15.505	6.125 (39.5%)	21.63
Strip	3.64	3.84	7.47	2.54 (34.0%)	10.01
Straw	5.29	4.24	9.53	2.77 (29.1%)	12.30

IN FY05 $

Fully loaded (incl.overheads & fringes)

BTeV / Co

Total Construction Cost
Pixel Detector

BTeV - WBS 1.2 Pixel Detector

24Mar04

Total Construction Costs

Fermilab Labor: Salary, OPTO, Vacation, Fringe & Overhead
Non-Fermilab Labor: Salary, Benefits & Overhead
No Escalation, No Full material Procurement 'Burdening'

Activity ID	Activity Description	Material & Services Cost	Labor Cost	Base Budget	Labor Contingency ($)	Materials & Services Contingency ($)	Total Budget (Base + Contingency)
CONSTRUCTION							
		$8,057,051	$7,448,777	$15,505,828	$2,729,894	$3,394,903	$21,630,627
1 -- Sensors and Pixel Detector Hybridization							
		$1,984,416	$345,387	$2,329,804	$109,674	$929,367	$3,368,846
2 -- Pixel Detector Electronics							
		$3,337,168	$918,110	$4,255,279	$334,155	$1,238,780	$5,828,215
3 -- Mechanical, Cooling and Vacuum System							
		$1,873,021	$2,701,470	$4,574,492	$972,570	$850,861	$6,397,925
4 -- System Integration & Testing							
		$792,327	$2,727,281	$3,519,609	$1,180,295	$360,107	$5,060,011
5 -- Pixel Detector Subproject Management							
		$70,116	$756,526	$826,642	$133,198	$15,787	$975,628
6 -- Level 1 & Inter-Subproject Link Milestones							
		$0	$0	$0	$0	$0	$0

BTeV/C0

Total Construction Cost Forward Straw Tracker

24Mar04

BTeV - FNAL Forward Tracker Straw Detector

Total Construction Costs

Fermilab Labor: Salary, OPTO, Vacation, Fringe & Overhead

Non-Fermilab Labor: Salary, Benefits & Overhead

No Escalation, No Full material Procurement 'Burdening'

Activity ID	Activity Description	Material & Services Cost	Labor Cost	Base Budget	Labor Contingency ($)	Materials & Services Contingency ($)	Total Budget (Base + Contingency)
CONSTRUCTION							
		$5,289,565	$4,238,558	$9,528,123	$1,387,701	$1,382,970	$12,298,795
1 -- Straw Chambers							
		$3,096,143	$2,636,773	$5,732,916	$775,995	$709,462	$7,218,374
2 -- Straw Detector Electronics							
		$1,572,103	$635,350	$2,207,454	$277,118	$484,427	$2,969,000
3 -- Mechanical, Gas, Calibration & Other Support Systems							
		$300,200	$440,587	$740,787	$161,236	$90,060	$992,084
4 -- Integration & Testing							
		$247,926	$38,094	$286,021	$27,024	$77,061	$390,107
5 -- Forward Tracker Straw Detector Subproject Management							
		$73,191	$487,753	$560,944	$146,325	$21,957	$729,227
6 -- BTeV Project Milestones							
		$0	$0	$0	$0	$0	$0

Total Construction Cost
Silicon Strip Detector

24Mar04

BTeV - WBS 1.7 Forward Tracker Strip Detector

Total Construction Costs

Fermilab Labor: Salary, OPTO, Vacation, Fringe & Overhead

Non-Fermilab Labor: Salary, Benefits & Overhead

No Escalation, No Full material Procurement 'Burdening'

Activity ID	Activity Description	Material & Services Cost	Labor Cost	Base Budget	Labor Contingency ($)	Materials & Services Contingency ($)	Total Budget (Base + Contingency)
CONSTRUCTION							
		$3,638,381	$3,835,006	$7,473,388	$1,237,379	$1,299,486	$10,010,253
1 -- Sensors (SM)							
		$1,039,110	$48,754	$1,087,864	$13,661	$259,777	$1,361,304
2 -- Electronics							
		$1,285,838	$987,667	$2,273,506	$270,678	$396,151	$2,940,336
3 -- Mechanics & Cooling							
		$591,133	$392,113	$983,247	$175,430	$315,592	$1,474,270
4 -- Integration							
		$702,098	$1,324,481	$2,026,580	$496,083	$321,905	$2,844,568

Conclusion

- The BTeV tracking system has three elements: Pixel vertex detector, forward silicon tracker, and forward straw detector
- For all three detectors:
  - Baseline technical designs exist
  - Good progress has been made in the R&D, and issues raised at last review addressed
  - Detailed WBS leading to a base cost estimate and resource-loaded schedule for the construction of the baseline detector
  - We are ready to move on to the next phase of the project